CHARLES DARWIN UNIVERSITY

Family Name	
Given Names	
Student Number	
Teaching Period	Semester 2, 2016

FINAL EXAMINATION	DURATION
ENG476 – Control Engineering	Reading Time: **10** minutes Writing Time: **180** minutes

INSTRUCTIONS TO CANDIDATES

1. Answer all questions.
2. Note that questions ARE NOT of equal value.
3. Read ALL questions carefully.

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a RESTRICTED OPEN BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

Any hard copy, unannotated English dictionary is permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
Lecture Textbook/s (Unannotated)	1 x 20 Page Book

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Question 1 (2 marks)

A system has a transfer function of:

$$\frac{y(s)}{x(s)} = G(s) = \frac{1}{(2s+2)}$$

At t = 0 an input signal $x(t) = 4 \cdot \sin\left(2 \cdot t - \frac{\pi}{3}\right)$ is applied to this system.

Question 1.1 (1 mark)
Determine what approximately the amplitude of the output signal will be after a considerable time (t >> 1 [s])?

Question 1.2 (1 mark)
Derive the time domain function, y(t), which will approximate the output of the system after a considerable time (t >> 1 [s]).

Question 2 (2 marks)

Unit negative feedback is applied to an open loop system with transfer function

$$G(s) = \frac{3}{(s+4)(s+2)}$$

and controlled by a proportional (P) controller with gain K (K > 0).

Question 2.1 (1 mark)
Give the closed loop transfer function of the unit negative feedback control system with s and K as variables.

Question 2.2 (1 mark)
Determine the range of the value of K for which the damping ratio of the closed loop system $\zeta > 0.5$?

Question 3 (8 marks)

Open loop bode plot

Given below in Figure 1 is a Bode plot of a second order open loop system G(s). The system has no zeros, except at infinity.

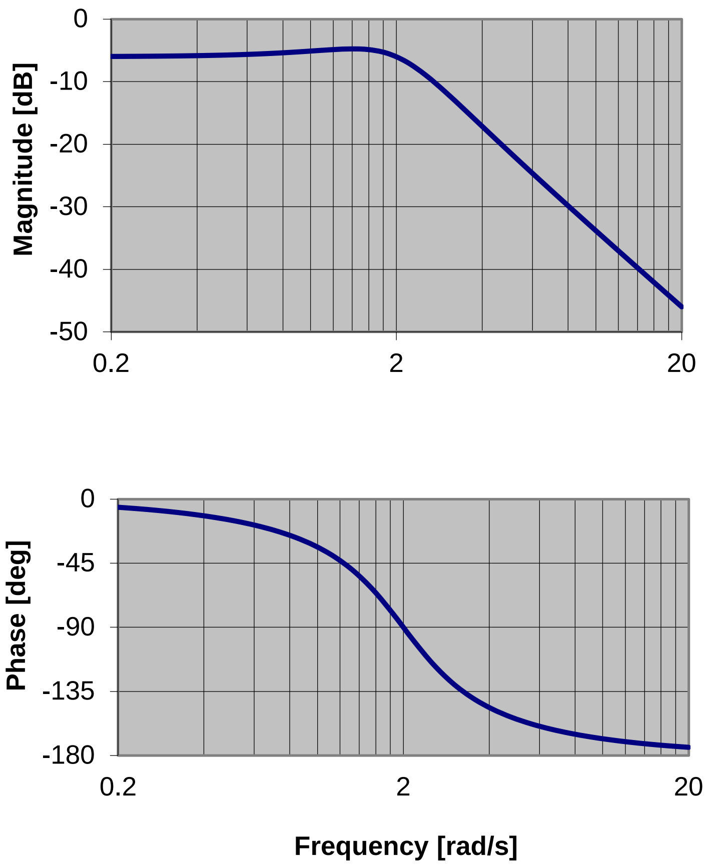

Figure 1, Bode plot of open loop system

Feedback control system

The open loop system $G(s) = \frac{c(s)}{u(s)}$ is being controlled by a unity feedback system with a lag compensator as controller $G_c(s) = \frac{u(s)}{e(s)}$, where e(s) = r(s) – c(s).

Specifications of control system:

It is required that the steady state error of the feedback control system is 16.67%. Furthermore, it is given that $G_c(s) \cdot G(s)$ should have a phase margin of 40 [deg].

Question 3.1 (1 mark)

Draw a block diagram of the closed loop system with r(s) as input and c(s) as output. Label the blocks and arrows appropriately.

Question 3.2 (1 mark)

Using Figure 1, determine the static gain (gain at ω=0 [rad/s]), the damping ratio ζ and the natural undamped frequency ω_n of G(s). Give the transfer function G(s).

Question 3.3 (1 mark)
Determine the static gain of the controller, K, which is needed to meet the steady state error specification.

Question 3.4 (1 mark)
Using Figure 1, show that the required phase margin of $G_c(s)\cdot G(s)$ cannot be achieved by using the proportional controller calculated in Question 3.3, i.e. $G_c(s) = K$.

Question 3.5 (1 mark)
Using Figure 1, determine a suitable time constant, T, for a compensator to meet the phase margin specification mentioned above. To do so, use 5 [deg] to compensate for the phase of the compensator and place the zero of the compensator one decade below the new gain crossover frequency (crossover frequency of $K\cdot G(s)$).

Question 3.6 (1 mark)
Determine the attenuation necessary to bring the magnitude curve of $G_c(s)\cdot G(s)$ down to 0 [dB] at the new gain crossover frequency.

Question 3.7 (1 mark)
Determine the transfer function $G_c(s)$ from the results of Question 3.2, 3.5 and 3.6.

Question 3.8 (1 mark)
If a PI controller were to be employed instead of a compensator, give at least one advantage and one disadvantage of using the PI controller instead of the compensator.

Question 4 (3 marks)

A linear open loop system G(s) can be modelled as two identical integrators in series followed by a first order system in series with the two integrators. The first order system has a time constant T = 2 [s] and a static gain (magnitude at ω = 0 [rad/s]) of 12 [dB]. A measured frequency response of a single integrator is shown in Figure 2 below.

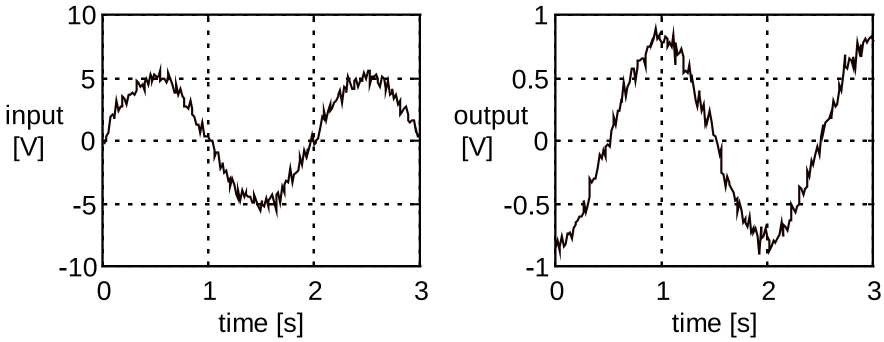

Figure 2, Measured frequency response of a single integrator

Question 4.1 (1 mark)
Determine the dominant frequency of the signals shown in the figure above and derive the transfer function of the two integrators in series.

Question 4.2 (1 mark)
Derive the transfer function of the first order system and determine G(s).

Question 4.3 (1 mark)
Unit negative feedback is applied to this system. Determine whether the closed loop system is stable. Explain your answer.

Question 5 (3 marks)

A system with transfer function G(s) has three poles and no zeros. The poles are located at $-2+\sqrt{3}\,j$, $-2-\sqrt{3}\,j$ and $-\alpha$. The static gain (magnitude at $\omega = 0$ [rad/s]) of the system is –6 [dB].

Question 5.1 (1 mark)
Determine the denominator of the transfer function G(s) as a polynomial in s with real coefficients and α as variable.

Question 5.2 (1 mark)
Determine the transfer function G(s) with α and s as variables.

Question 5.3 (1 mark)
Discuss qualitatively how the overshoot and rise time are affected by α when α is changed from ∞ to 0.

Question 6 (2 marks)

Given the state variable equations of an open loop system:

$$\frac{dx(t)}{dt} = \begin{bmatrix} 1 & -2 \\ 1 & 0 \end{bmatrix} \cdot x(t) + \begin{bmatrix} 2 \\ 0 \end{bmatrix} \cdot u(t) \text{ and } y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} \cdot x(t)$$

Question 6.1 (1 mark)
Determine the open loop transfer function G(s) that describes the input-output relation of the state space system in the Laplace domain. Is the open loop system stable? Explain your answer.

Question 6.2 (1 mark)
Determine the state feedback matrix K of the state feedback controller $u(t) = -K\cdot x(t)$ which locates the closed loop poles at s = -2 and s = -3.